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(54) Abstract Title

# MULTI-USER DETECTION IN A CDMA COMMUNICATION SYSTEM

(57) A method and device for multi-user detection in a CDMA communication system utilizes preconditioning 170, 180 of a correlation matrix by multiplication so as to set to unity the diagonal sub-matrix of the resultant matrix. The resultant matrix is used for serial interference cancellation 150 reducing the number of iterations. A block Toeplitz matrix method is employed to simplify the calculations. This offers the advantages of reduced computaional complexity, reduced power consumption and decoding delay. A further advantage is to implement other algorithms on the same multi-user detection digital signalling processor (DSP), via reduced MIPS and/or hardware.

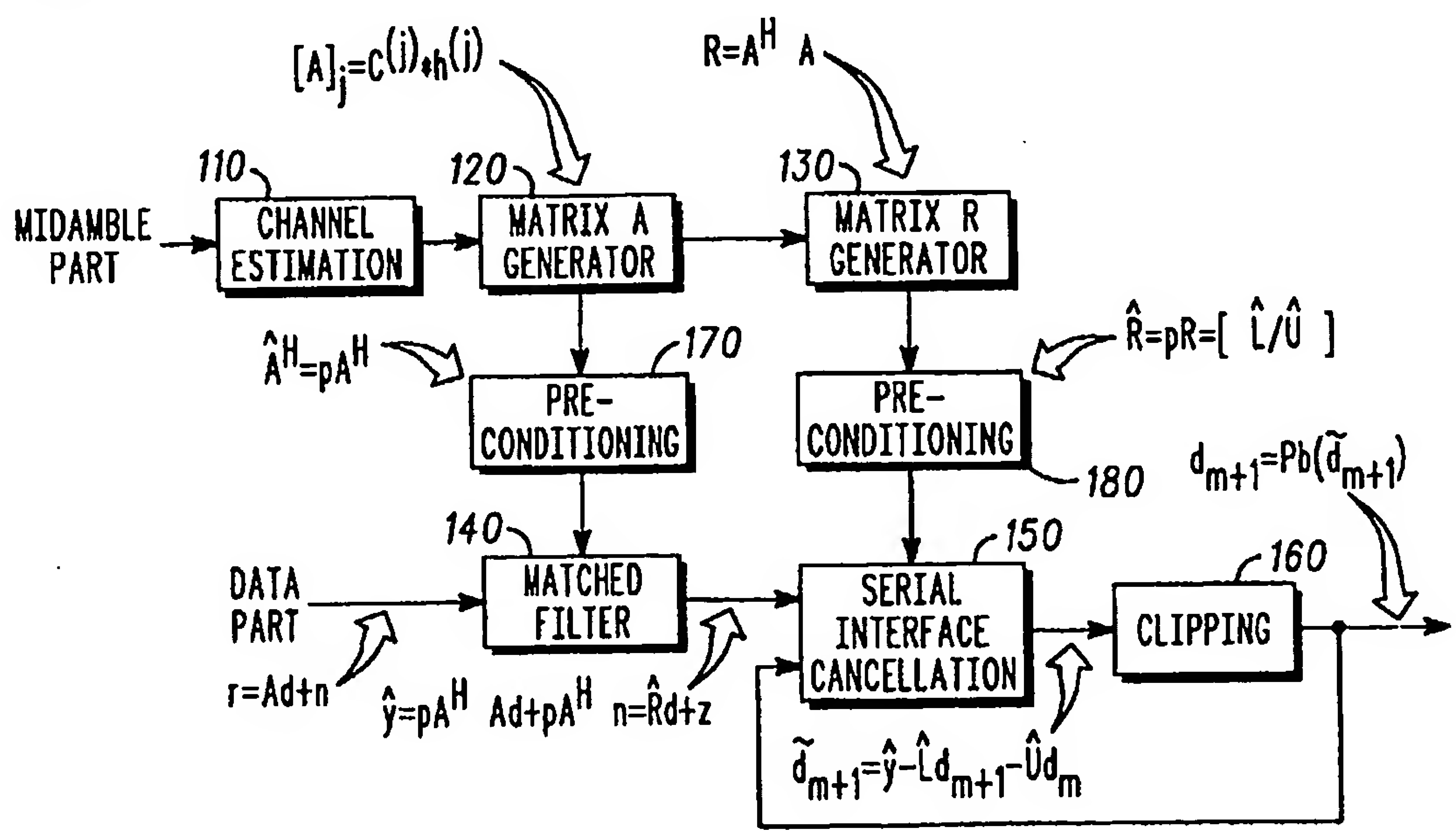


*FIG. 2*

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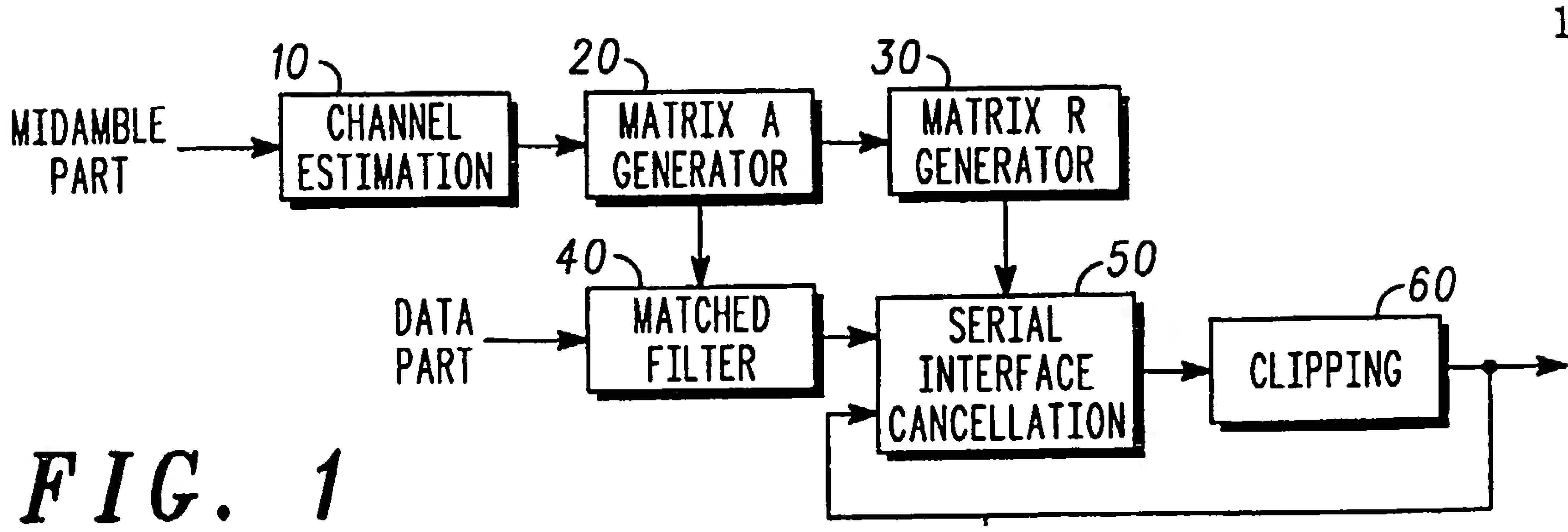


FIG. 1

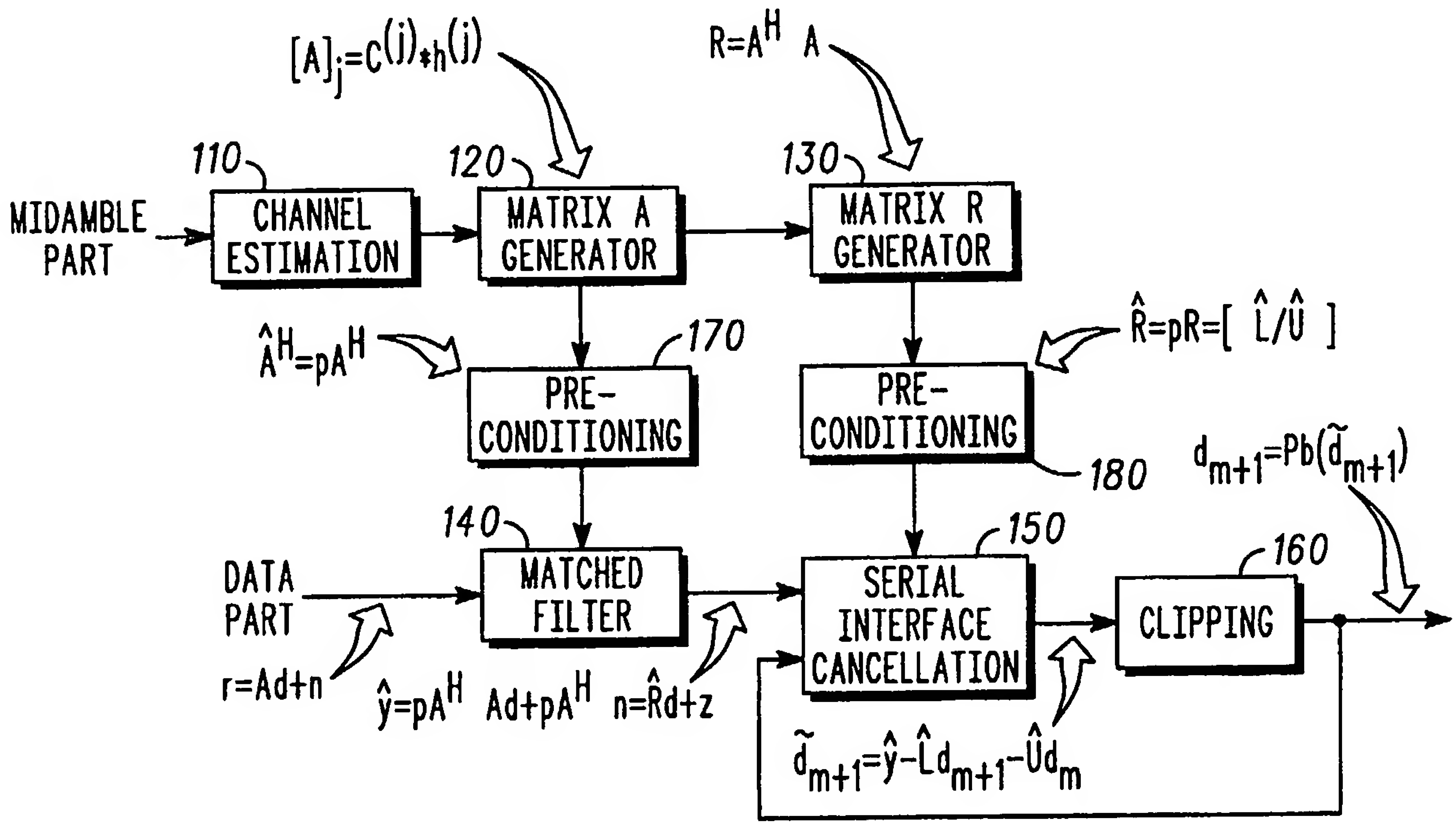


FIG. 2

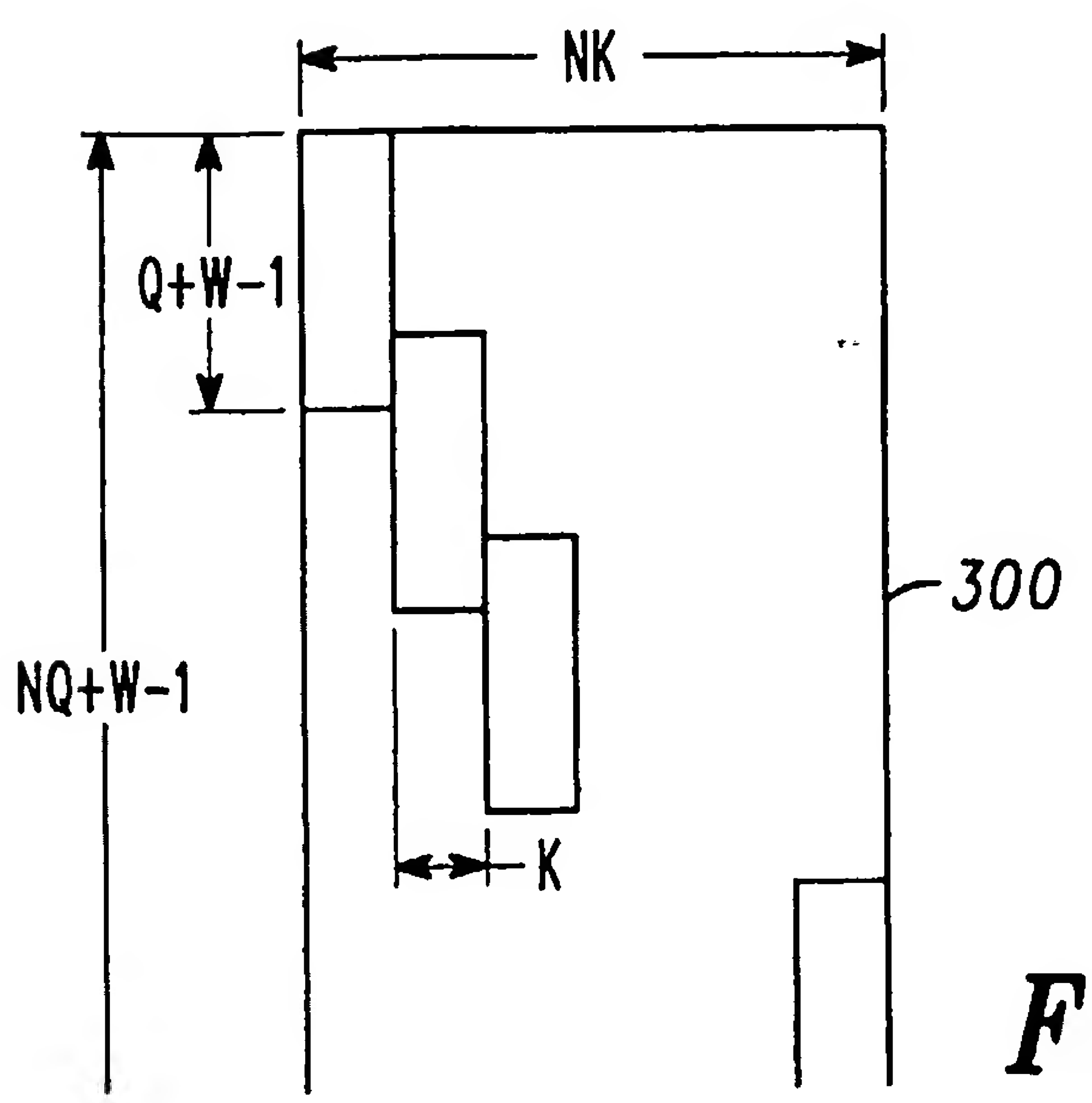


FIG. 3

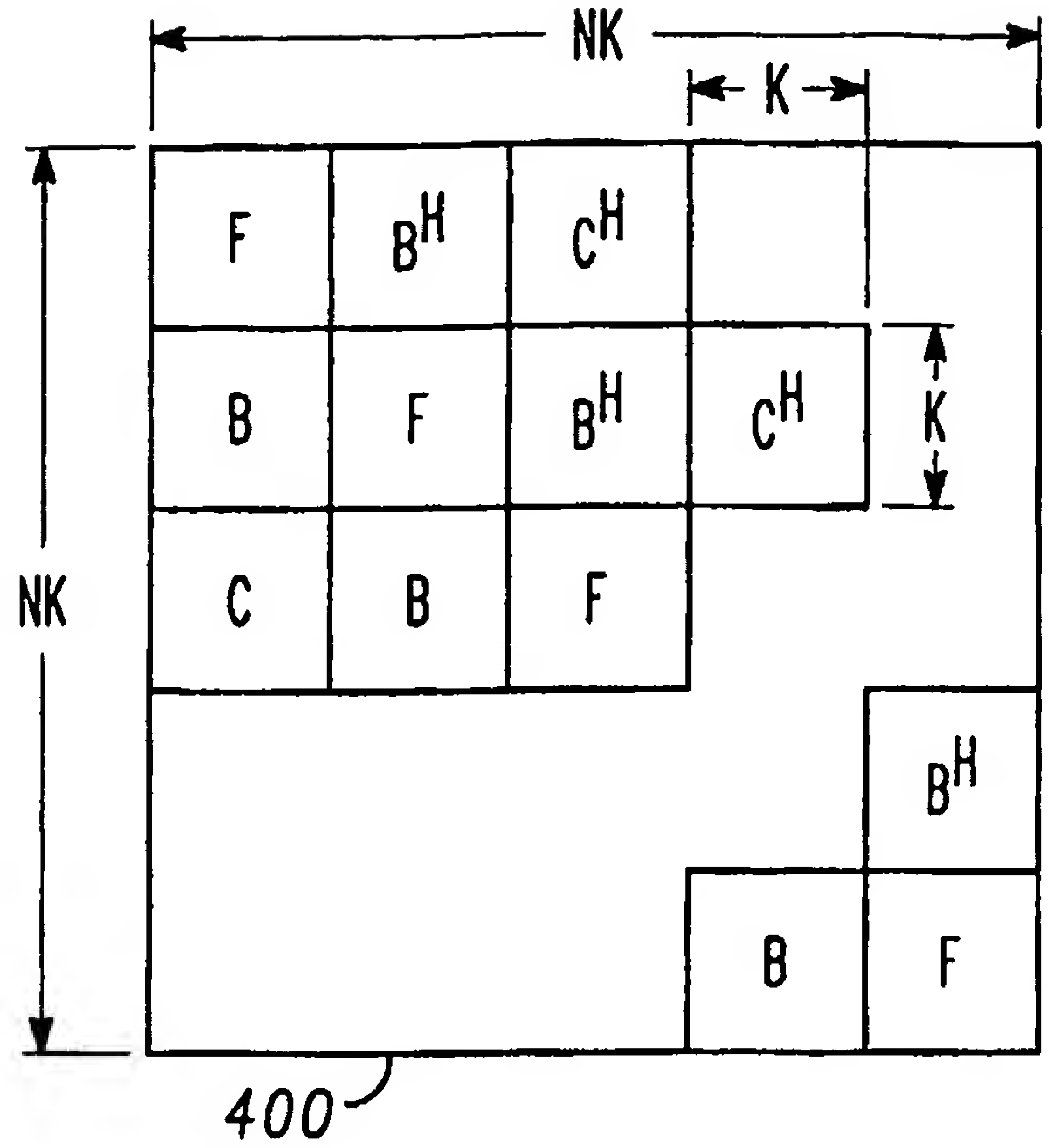


FIG. 4

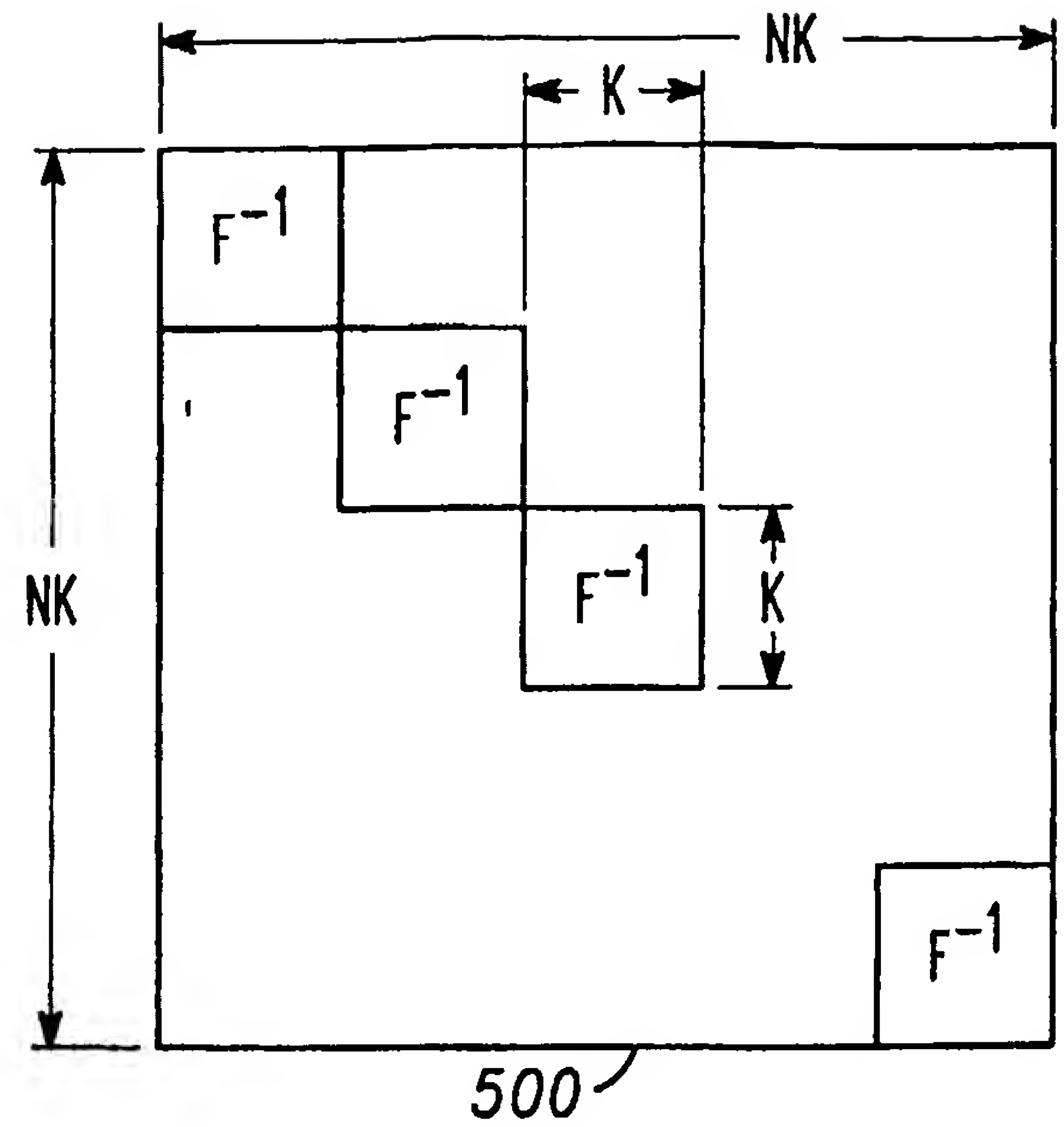


FIG. 5

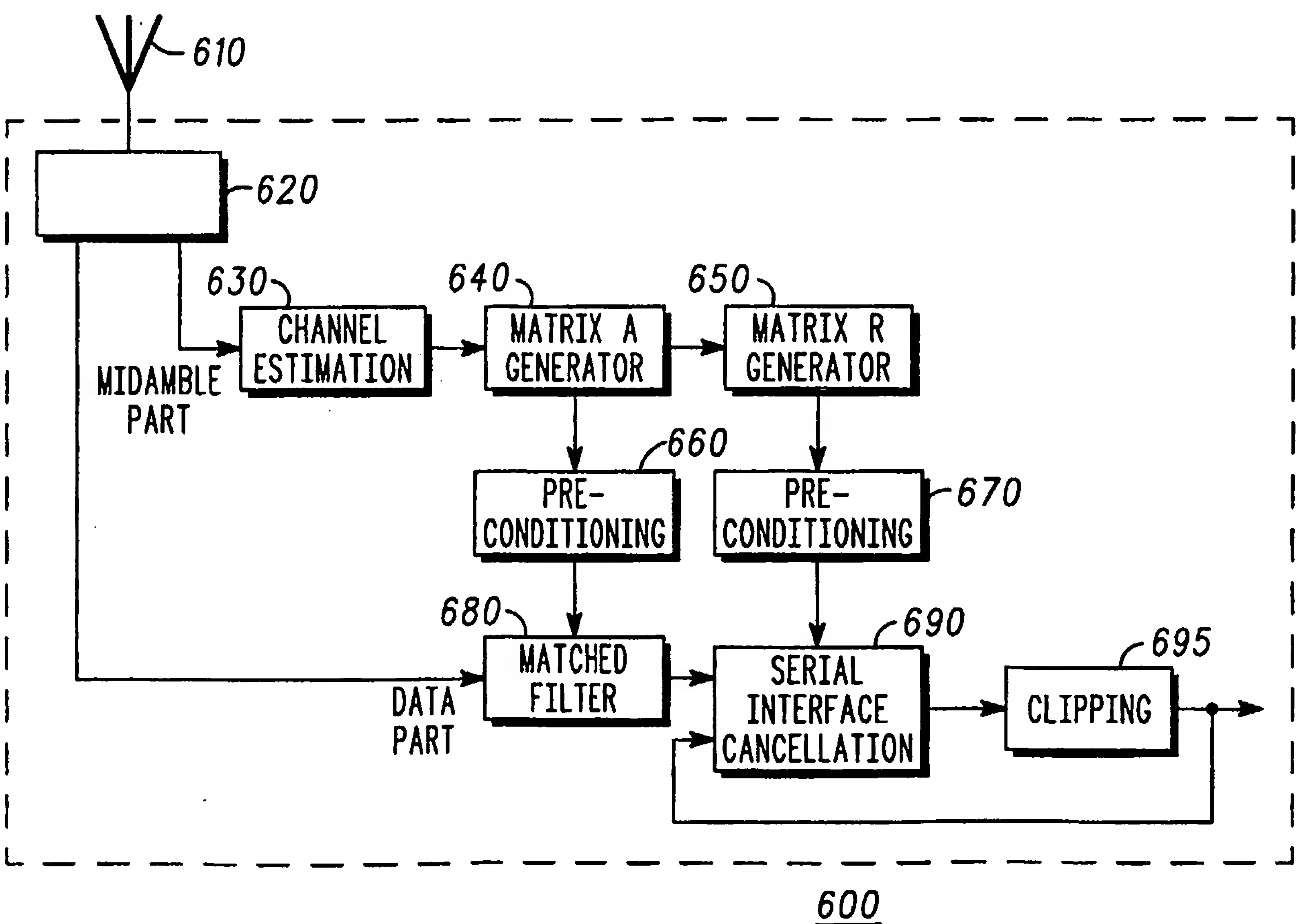


FIG. 6

# METHOD AND DEVICE FOR MULTI-USER DETECTION IN CDMA CHANNELS

## Field of the Invention

This invention relates to CDMA based communication systems (like UMTS-TDD), and particularly to multi-user detection in such systems using serial interference cancellation.

## Background of the Invention

Third generation cellular standards are based on code division multiple access (CDMA). The presence of both multiple-access interference (MAI) and inter-symbol interference (ISI) constitute a major impediment to reliable communication in CDMA channels. Often, the conventional single user detection, based on the RAKE receiver, does not provide adequate performance.

Over the past few years, a significant amount of research has addressed the problem of multi-user detection in order to mitigate the effects of MAI and ISI. An optimal solution to this problem, the Maximum Likelihood Multi-User Sequence Estimator (MLMSE) was developed and was shown to achieve a significant performance improvement over that of a conventional RAKE receiver. The MLMSE is implemented with a bank of matched filters followed by a Viterbi algorithm, in a similar way to the MLSE equalization applied to TDMA ISI channels. Unfortunately,

this optimal solution is too complex for real-time implementations as the number of states in the trellis is exponential with the number of users and with the length of the channel filter (length of ISI).

A considerable amount of sub-optimal multi-user detection schemes have been proposed over the last few years, offering a range of performance versus complexity trade-off. Linear equalizers based on Zero Forcing Block Linear Equalization (ZF-BLE) or Minimum Mean Square Error Block Linear Equalization (MMSE-BLE) criterion are two of the popular multi-user schemes. For most real-time applications, however, their complexity is still considered to be too high.

Another known group of sub-optimal solutions are the Interference Cancellation (IC) schemes. These schemes have received much attention due to their relative computational simplicity. It has been shown that the IC schemes can be viewed as iterative methods to achieve the ZF-BLE and the MMSE-BLE solutions. The computational complexity of these schemes depends on their convergence rate (i.e., how many iterations are required to converge to the performance of ZF-BLE and MMSE-BLE schemes).

Partial/weighted interference cancellation tries to reduce the number of required iterations by introducing a variable weight in each iteration. However, although known methods of partial/weighted interference cancellation reduce the number of required iterations, the required number of iterations is still too high for applications such as portable devices where power

consumption is a prime consideration.

Parallel interference cancellation has been suggested as a way to reduce decoding delay. However, parallel interference cancellation increases the number of required iterations.

Recently, a new type of serial interference cancellation (SIC) scheme has been proposed which is shown to converge to the so-called box-constrained maximum likelihood solution, which performs better than the BLE methods and can be considered a compromise between the optimal ML solution and the BLE solutions. The convergence rate of this scheme is dependent on the number of users (or more precisely, the number of active spreading codes) and the Signal-to-Noise ratio (SNR). For implementation of this algorithm in terminals, it is important that the number of required iterations is reduced in order to maintain a low complexity multi-user detection scheme.

In such a system, the received signal $r$ is given by:

$$r = A\,d + n \tag{1}$$

where $A$ is a matrix representing the spreading codes and the multipath channel, $d$ is a vector representing the symbols to be detected, and $n$ is a vector of additive white Gaussian noise.

The multi-user detection problem can be stated as follows:

Given the observations (received signal) $r$, the spreading codes and the channel impulse response (which have to be

evaluated at the receiver), estimate the transmitted symbols vector $d$.

The outputs of a matched filter are:

$$y = A^H Ad + A^H n = Rd + z \qquad (2)$$

The resulting correlation matrix $R$, has a block Toeplitz structure, as shown in FIG. 4.

Known box-constrained maximum likelihood solutions for $d$ still require a high number of iterations to achieve convergence.

A need therefore exists for a method and device for multi-user detection in CDMA channels wherein the abovementioned disadvantage(s) may be alleviated, allowing the number of iterations which are necessary to achieve convergence to be reduced, thus reducing complexity, power consumption and decoding time.

**Statement of Invention**

In accordance with a first aspect of the present invention there is provided a method for multi-user detection in CDMA channels as claimed in claim 1.

In accordance with a second aspect of the present invention there is provided a device for multi-user detection in CDMA channels as claimed in claim 6.

**Brief Description of the Drawings**

One method and device for multi-user detection in CDMA channels incorporating the present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

FIG. 1 shows a schematic block diagram of a known weighted serial interference cancellation (SIC) detection scheme;

FIG. 2 shows a schematic block diagram of a serial interference cancellation (SIC) detection scheme utilizing the present invention;

FIGS. 3, 4 and 5 show representations of matrices used in the SIC detection scheme of FIG. 2; and

FIG. 6 shows a block schematic diagram of a portable CDMA communication device for performing the method of FIG. 2.

**Description of Preferred Embodiments**

In a CDMA detection scheme, as discussed above, the received signal $r$ is given by the equation *(1)*, and the maximum likelihood (ML) solution to $\boldsymbol{d}$ is:

$$\tilde{d} = \arg\min \left\| r - A\hat{d} \right\|^2 , \quad \hat{d} \in V \qquad (3)$$

where $V$ is the symbol alphabet. For QPSK, $V = \{1+j,\ 1-j,\ -1+j,\ -1-j\}$.

The solution is obtained with the Viterbi algorithm. The number of states in the trellis is exponential with the number of users and the ISI length. Therefore, the optimal solution is too complex for real time implementations.

The unconstrained maximum likelihood solution (where $d$ can take any complex value) is obtained with the zero forcing block linear equalizer (ZF-BLE) detector. In a box-constrained ML, $d$ can take any complex value within a specific closed region (box). An efficient iterative algorithm for solving the box constrained ML problem is:

$$\tilde{d}_{m+1} = \mu P_b[\tilde{d}_m - wE(R\tilde{d}_m - y + K(\tilde{d}_{m+1} - \tilde{d}_m))] \qquad (4)$$

where $m$ is the iteration number, $y$ is the matched filter output vector ($y = A^H Ad + A^H n = Rd + z$), $0 \leq \mu \leq 1$, $w > 0$, $E$ is any positive diagonal matrix, $K$ is either strictly lower triangular, strictly upper triangular or null(0), and $P_b$ is a clipping function, such that:

$$P_b(x) = \min(\max(x_R - 1),1) + j\min((\max(x_I,-1),1) \qquad (5)$$

where $x_R$ and $x_I$ are respectively the real and imaginary parts of $x$.

It can be shown that a special case of this algorithm is the weighted serial interference cancellation (weighted SIC). From equation *(4)* above, by decomposing $R$ to $R=L+D+U$ (where $L$ is lower triangular, $D$ is diagonal and $U$ is upper triangular, the following expression can be derived:

$$\tilde{d}_{m+1} = P_b[D^{-1}(y - Ld_{m+1} - Ud_m)] \tag{6}$$

An important result from this choice of parameters is that the SIC convergence is guaranteed. Another expression, which corresponds to the weighted SIC, can be obtained by choosing $w \neq 1$:

$$\tilde{d}_{m+1} = P_b[(1-w)d_m + wD^{-1}(y - Ld_{m+1} - Ud_m)]$$

The weighted SIC is used to accelerate the convergence of the SIC. Unfortunately, it is difficult to calculate the optimal value of $w$ and it has to be determined through simulations. For the weighed SIC, convergence is guaranteed for $0 \leq w \leq 2$.

The resulting multi-user algorithm is presented in FIG. 1, in which a midamble portion of a received CDMA message is used for channel estimation (10) and to generate a matrix $A$ (20) (representing the spreading code and the multipath channel) and a correlation matrix $R$ (30), and a data part of the received CDMA message is applied to a matched filter (40) and a serial interface cancellation unit (50) which receive respectively the matrices $A$ and $R$. A clipping unit (160) may be used to improve detector performance. Unfortunately, such a weighted SIC still requires a high number of iterations to achieve convergence.

The present invention proposes a scheme to accelerate the convergence of the SIC, with minimal loss of performance, as will be described below.

In order to reduce the number of iterations and the computational complexity a modified block serial interference cancellation (BSIC) is suggested. The inventors have observed that the correlation matrix $R$ is block Toeplitz and that the largest off-diagonal elements are in the main diagonal sub-matrix. Therefore, the inventors have realized, a pre-multiplication of $R$, to cause the diagonal sub-matrix to be unity, may result in a more rapid convergence. This pre-multiplication is far less processor intensive than one iteration, as will be discussed, and thus reduces the overall computational complexity of the detection.

In the following description, the symbols $K$, $N$, $Q$ and $W$ are used to represent values as follows:

$K$ is the number of users (or number of active codes);

$N$ is the number of symbols to be detected;

$Q$ is a spreading factor; and

$W$ is the channel length (in chips).

If the pre-multiplication matrix is defined as:

$$P = I_{N\times N} \otimes F^{-1}{}_{K\times K} \tag{7}$$

where $F^{-1}{}_{K\times K}$ is the inverse of the $K\times K$ sub-matrix of $R$, $I_{N\times N}$ is an $N\times N$ identity matrix, and $\otimes$ denotes a Kronecker product, then the result $P$ is an $NK\times NK$ matrix having a block Toeplitz structure.

This matrix is used to pre-multiply the correlation matrix $R$ and the matched filter outputs:

$$\hat{R} = P\times R \tag{8}$$

and

$$\hat{y} = P \times y \tag{9}$$

The interference cancellation can now be described by:

$$\tilde{d}_{m+1} = P_b[\hat{y} - \hat{L}d_{m+1} - \hat{U}d_m)] \tag{10}$$

and

$$\hat{R} = \hat{L} + I + \hat{U} \tag{11}$$

where $\hat{L}$, $I$ and $\hat{U}$ are the lower, diagonal and upper parts, respectively, of the new matrix $\hat{R}$.

It may be noted that in the new matrix $\hat{R}$ the diagonal now is '1'.

It may also be noted that now the cancellation in each iteration can be done in parallel for all the codes for each symbol n. This follows from the fact that the $K \times K$ sub-matrix in the diagonal of $\hat{R}$ is unity (indicating no interference between codes in the same symbol period).

The resulting multi-user algorithm is illustrated in FIG. 2, in which a midamble portion of a received CDMA message is used for channel estimation (110) and to generate a matrix $A$ (120) (representing the spreading code and the multipath channel) and a correlation matrix $R$ (130), and a data part of the received CDMA message is applied to a matched filter (140) and a serial interface cancellation unit (150) which receive respectively the matrices $A$ and $R$, now pre-multiplied (160, 170) by a pre-conditioning matrix $P$ as described above. A clipping unit (160) is used to improve detector performance in known manner. For convenience, as will be discussed below, the

matrices $A$, $R$ and $P$ are all of block Toeplitz structure, (matrix $A$ being of size $NK \times NQ+W-1$, with sub-matrix blocks of size $K \times Q+W-1$, as represented by the matrix 300 in FIG. 3; matrix $R$ being of size $NK \times NK$, with sub-matrix blocks of size $K \times K$, as discussed above, as represented by the matrix 400 in FIG. 4; and matrix $P$ being of size $NK \times NK$, with sub-matrix blocks of size $K \times K$, as represented by the matrix 500 in FIG. 5). The pre-conditioning matrix $P$ is chosen to be of low complexity, and to not increase the number of non-zero elements when multiplying the matrix $R$ to convert to unity its diagonal elements as discussed above.

The convergence rate for the known SIC detection scheme and for the BSIC scheme incorporating the invention has been simulated, and the results of the simulation for different numbers of users are shown in the following table.

| Number of Users | SIC Iterations | BSIC Iterations |
|---|---|---|
| 2-3 | 2 | 1 |
| 4-7 | 3 | 1 |
| 8-9 | 4 | 1 |
| 10 | 5 | 1 |

Table 1: Convergence Rate of SIC and BSIC Schemes

Performance tests have confirmed that the BSIC scheme incorporating the invention as described above achieves generally similar performance compared to the weighted

SIC scheme discussed above, while providing accelerated convergence as described. Performance tests have confirmed that the BSIC scheme incorporating the invention as described above achieves accelerated convergence performance while providing substantially the same performance as the ZF-BLE scheme discussed above.

An analysis of computational complexity shows that the BSIC iteration in the scheme described above requires less computation than the SIC scheme discussed above. In a practical example of computational complexity (considering typical operational parameters of: active codes = 16, spreading factor = 16, channel length (in chips) = 57, and number of symbols in a data field = 61) the computational complexity of the two schemes was shown to be:

| | SIC | BSIC |
|---|---|---|
| Preliminary Stages | 161 MIPS | 175 MIPS |
| MIPS per Iteration | 89 MIPS | 74 MIPS |

Table 2: Computational Complexity of SIC and BSIC Schemes

Since the SIC scheme requires more iterations than the BSIC scheme, it can be seen that the total computational complexity of BSIC is significantly lower.

Thus, in summary it will be appreciated that the above-described method efficiently reduces the computational complexity of serial interference cancellation in asynchronous CDMA channels. It will be understood that the reduced complexity is achieved by accelerating the

convergence rate of an algorithm by a preconditioning technique in which a preconditioning matrix is chosen such that the computational complexity of the preconditioning stage is very low (and is largely independent of the number of symbols to be detected), producing significant acceleration. Simulations performed in a TDD link simulator indicate that only one iteration is required for convergence for 10 or fewer users for low and moderate SNR values. It will be understood that the low complexity of the preconditioning stage is achieved by using the block Toeplitz structure of the matrices $A$, $R$ and $P$.

Referring now to FIG. 6, a radio transceiver 600, for use in a CDMA communication system, for performing the method described above in relation to FIG. 2 has an antenna 610 coupled to a radio transceiver section 620. Signals received at the antenna 610 are passed to the receiver part of the transceiver section 620 and RAKE-filtered in known manner to derive a midamble part and a data part of the received signal. The midamble portion is applied to a channel estimation unit 630 for channel estimation in known manner, to a matrix generator 640 for generating a matrix A (representing the spreading code and the multipath channel) in known manner and to a matrix generator 650 for generating a correlation matrix R in known manner. The matrices A and R are pre-conditioned as described above in pre-conditioners 660 and 670 respectively. The data part of the received CDMA signal is applied to a matched filter 680 and a serial interface cancellation unit 690. A clipping unit 695 is used, in known manner, to improve detector performance. The

elements 630-670 of the transceiver 300 may typically be of provided in a microcontroller or digital signal processor (DSP) (not shown) as usual in a portable cellular radio transceiver.

It will be understood that the method and device for multi-user detection scheme in CDMA channels described above provides the following advantages:

a. Reduced computational complexity
b. Reduced power consumption (because of the reduced complexity).
c. Reduction of decoding delay (because of the reduced number of iterations)
d. The ability to implement other algorithms on the same multi-user detection DSP (reduced MIPS) and/or reduced hardware.

**Claims**

1. A method for multi-user detection in a CDMA communication system, comprising:

estimating channel conditions from a received signal;

generating a first matrix representative of spreading code and the multipath channel conditions in the received signal;

pre-conditioning the first matrix;

generating a second correlation matrix;

pre-conditioning the second correlation matrix;

filtering data in the received signal with the pre-conditioned first matrix;

processing the filtered data with the pre-conditioned second matrix to perform serial interference cancellation.

2. The method of claim 1 wherein the step of pre-conditioning the second matrix comprises multiplying the second matrix by a preconditioning matrix so as to set to unity the resultant matrix's diagonal sub-matrix.

3. The method of claim 1 or 2 further comprising employing partial interference cancellation to accelerate further convergence.

4. The method of claim 1, 2 or 3 further comprising clipping the signal after serial interference cancellation.

5. The method of claim 2, or of claim 3 or 4 when dependent from claim 2, wherein the first, second and preconditioning matrices are block Toeplitz matrices.

6. A device for multi-user detection in a CDMA communication system, comprising:

means for estimating channel conditions from a received signal;

means for generating a first matrix representative of spreading code and the multipath channel conditions in the received signal;

means for pre-conditioning the first matrix;

means for generating a second correlation matrix;

means for pre-conditioning the second correlation matrix;

means for filtering data in the received signal with the pre-conditioned first matrix;

means for processing the filtered data with the pre-conditioned second matrix to perform serial interference cancellation.

7. The device of claim 6 wherein the means for pre-conditioning the second matrix is adapted to multiply the second matrix by a preconditioning matrix so as to set to unity the resultant matrix's diagonal sub-matrix.

8. The device of claim 6 or 7 further comprising means for partial interference cancellation to accelerate further convergence.

9. The device of claim 6, 7 or 8 further comprising means for clipping the signal after serial interference cancellation.

10. The device of claim 7, or of claim 8 or 9 when dependent from claim 7, wherein the first, second and preconditioning matrices are block Toeplitz matrices.

11. A method for multi-user detection in a communication CDMA system substantially as hereinbefore described with reference to FIGS. 2-5 of the accompanying drawings.

12. A device for multi-user detection in a communication CDMA system substantially as hereinbefore described with reference to FIG. 2-6 of the accompanying drawings.

| | | | |
|---|---|---|---|
| **Application No:** | GB 0111527.8 | **Examiner:** | Dr Jan Miasik |
| **Claims searched:** | 1-12 | **Date of search:** | 19 December 2001 |

# Patents Act 1977
# Search Report under Section 17

**Databases searched:**

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.S): H4P(PAN, PDCSL)

Int Cl (Ed.7): H04B, H04J

Other: Online: WPI, EPODOC, JAPIO

**Documents considered to be relevant:**

| Category | Identity of document and relevant passage | | Relevant to claims |
|---|---|---|---|
| Y | EP 0971485 A1 | (Siemens Aktiengesellschaft): whole document, particularly p6, lines 9-24 | 1 at least |
| Y | EP 0717505 A2 | (NTT Mobile Communications Network Inc.): whole document, particularly col.7, lines 3 to 12 and figs. 3a, 3b, 14a and 14b | 1 at least |
| Y | US 6182270 B1 | (Feldmann *et al.*): whole document, particularly cols. 3-7 | 1 at least |

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